AD A030890

REPORT NO. NADC-76274-30

COATINGS FOR ELECTRICAL CONNECTOR SHELLS

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13 AUGUST 1976

PROGRESS REPORT
AIRTASK NO. WF 54-593-201
Work Unit No. ZM 301

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Prepared for
NAVAL AIR SYSTEMS COMMAND
Department of the Navy
Washington, D.C. 20361

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER: NADC-76274-30	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle): COATINGS FOR ELECTRICAL CONNECTOR SHELLS		5. TYPE OF REPORT & PERIOD COVERED: PROGRESS 1 Jul 75 - 1 Jv 76
		6. PERFORMING ORG. REPORT NUMBER: NADC-76274-30
7. AUTHOR(s): EDWARD J. JANKOWSKY		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Naval Air Development Center, Air Vehicle Technology Department, Warminster, Pennsylvania 18974		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: AIRTASK NO. WF 54-593-201, Work Unit No. ZM 301
11. CONTROLLING OFFICE NAME AND ADDRESS: Naval Air Systems Command, Department of the Navy, Washington, DC 20361		12. REPORT DATE: 13 Aug 1976
		13. NUMBER OF PAGES: 29
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report): UNCLASSIFIED
		15a. DECLASSIFICATION DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for Public Release; Distribution Unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Electrical connector shells
Corrosion
Protective coatings

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Coatings for improved corrosion protection of aluminum alloy connector shells have been investigated with a view toward replacing currently employed coatings. Cyclic heating/corrosion tests as well as SO_2-salt spray exposure have indicated that duplex electroless nickel-cadmium coatings protect 6061 aluminum alloy well if they are thick enough (17.8 μm (.0007")). Use of these coatings is recommended.

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SUMMARY

INTRODUCTION

Electrical connector shell corrosion has been a recurring problem in naval aircraft. The aluminum alloy shells corrode under the currently used coating, electroless nickel. Eventually, the coating lifts and breaks under the force of corrosion products and corrosion continues at a faster rate until a good part of the aluminum is eaten away even though the nickel coating itself is not corroded. A more corrosion resistant coating is needed to prevent failures of this type. This report covers an attempt to find a better coating for use up to 200°C.

Standardized panels of 6061-T6 aluminum alloy were used for this work rather than actual connector hardware because of the variety and configurational complexity of the connector types involved.

This investigation was authorized by AIRTASK NO. WF 54-593-201, Work Unit No. ZM 301.

SUMMARY OF RESULTS

Results of cyclic heating corrosion tests indicate that cadmium over electroless nickel protects 6061 aluminum alloy through the full test period (25 cycles of 16 hours at 200°C followed by 32 hours in 5% salt spray) with almost no pitting. For good protection, the minimum total thickness of the coating system was found to be 17.8 μm (.0007"). Either layer could be as thin as 5.1 μm (.0002") provided the other layer made up the remaining thickness to make a total of 17.8 μm (.0007"). It was also found that a coating cycle consisting of electroless nickel plate, bake one hour at 149°C, cadmium plate, chromate treat, and bake one hour at 149°C, was required for best results, since some coatings that met the thickness requirements failed if they were not baked. Thick cadmium, 25.4 μm (.001"), with a chromate coating also shows good protection in this test, while thinner cadmium coatings fail in less than 25 cycles. The best strike coating for cadmium was found to be the copper strike. Cadmium or bronze strikes were considered to be unsatisfactory. The electroless nickel "strike" (actually 2.5 μm (.0001") thick) was a great improvement over the others, but still failed one panel in less than 25 cycles. Electroless nickel alone failed in 11 cycles or less in all thicknesses tested up to 25.4 μm (.001").

Nickel-cadmium (chromated and baked) provided good protection to the basis metal during SO_2-salt spray exposure for 168 hours, showing some blistering but no pitting. Cadmium was pitted and corroded and electroless nickel failed very badly. Similar tests with cadmium and nickel-cadmium in standard 5% salt spray showed similar results in that scribed panels exhibited more corrosion in cadmium plated panels than in nickel-cadmium plated panels.

Results of dissimilar metal tests were not very informative (168 hours in 5% salt spray). Corrosion between bare 7075-T6 and the various coated panels was not much different from corrosion between bare 6061-T6 and bare 7075-T6

aluminum alloys. Results with coated panels coupled with titanium 6Al-4V alloy showed slightly more pitting along the edges of the joined panels, but minor corrosion otherwise.

Electroless nickel looked good in extended baking (100 hours at 200°C) followed by 500 hours of salt spray exposure, a finding contrary to service experience. Cadmium was pitted in thicknesses less than 25.4 μm (.001"), while only one of three panels showed more than six pits for the 25.4 μm coating. Nickel-cadmium again passed this test with only one distinct pit on one panel and very general corrosion and darkening otherwise (no pits).

CONCLUSIONS

1. Of the coatings tested, cadmium over electroless nickel offers the best protection to 6061-T6 aluminum alloy.

2. Baking is necessary after each layer of a nickel-cadmium coating is applied to assure good adhesion and corrosion resistance.

3. Electroless nickel is an unsatisfactory coating for the corrosion protection of 6061-T6 aluminum alloy.

4. Cadmium coating, 25.4 μm thick, offers the second best protection to 6061 although this coating is easier to scratch than nickel-cadmium and corrodes more readily in the scratched area.

5. Cyclic corrosion testing is a satisfactory method for estimating service behavior of coatings for electrical connectors.

6. With few exceptions, if a coating does not fail in 10 cycles or less it will not fail in 25 cycles.

7. Results of SO_2-salt spray exposure correlate well with service experience.

8. Results of 100 hours of heating at 200°C followed by 500 hours in salt spray do not correlate with service experience.

9. Thin cadmium coatings (Class 3, Type II, QQ-P-416) protect aluminum poorly in all the tests.

RECOMMENDATIONS

Based on the work conducted in this investigation, it is recommended that:

1. The coating system for aluminum alloy connector shells of the 200°C class be changed to cadmium over electroless nickel with a combined thickness of 17.8 μm (.0007") minimum and a thickness of cadmium ranging from 5.1 to 12.7 μm (.0002"-.0005") or more.

2. A ten cycle corrosion test be adopted for specification testing with each cycle consisting of 16 hours at 200°C followed by 32 hours in 5% salt spray.

3. Consideration be given to increasing the thickness requirement of connectors intended for low temperature service (85-125°C) from Class 3 of QQ-P-416, to Class 1, or the finish requirement of Recommendation 1.

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BACKGROUND

A considerable number of corrosion problems with electrical connector shells have been reported by field activities. A preliminary investigation of these failures indicated that the greatest number were encountered with aluminum shells designed for use at temperatures up to 200°C. Most of the connectors in this class (roughly 90%) are 6061 aluminum alloy; most are coated with electroless nickel. About 10% are aluminum casting alloys such as alloy 380 of QQ-A-591d. Coating thicknesses vary from about 12.7 μm (.0005") to slightly more than 25.4 μm (.001"). Failures have been in the form of severe undercutting and lifting of the electroless nickel coating while the basis metal, which is anodic to the coating, corrodes away underneath. The 6061 aluminum alloy is resistant to corrosion without a coating and would probably be protected well by a simple MIL-C-5541, Class 3, chemical conversion coating, but the aluminum is subject to seizing and galling and will not function on threaded connectors. The number of coatings that will perform well at 200°C is small, since the coatings must be electrically conductive. If it were not for this requirement, hard anodizing (MIL-C-8625, Type III) or even dichromate-sealed, sulfuric acid anodizing (MIL-C-8625, Type II) would serve. The newer metallic-ceramic coatings with low temperature cures might also be protective, but they are non-conductive unless higher curing temperatures (800°F or higher) are used. The most promising coatings appeared to be thicker cadmium coatings (17.8-25.4 μm (.0007"-.001")), or variations of a duplex electroless nickel-cadmium coating. It was also considered that strike coatings, other than the conventional copper strike employed for plating aluminum, might provide improved corrosion resistance under cadmium overcoats.

TEST METHODS

CYCLIC TESTING

Electrical connectors of the type involved in corrosion problems heat up for short periods during operation and remain at ambient temperatures in the corrosive environment while the equipment is not operating. It was, therefore, considered that a cyclic heating-salt spray test would most closely simulate actual service. The cycle chosen for laboratory tests was 16 hours at 200°C followed by 32 hours in 5% salt spray (ASTM B117-73). Initial screening was conducted using this cycle and 48.3 x 97.5 x 3.2 mm (2" x 4" x 1/8") panels of 6061-T6 aluminum alloy. Tests were discontinued when six pits or conspicuous blistering appeared on the panels. In some cases, the appearance of very small blisters was recorded, but testing was continued until six pits formed. Testing was stopped after twenty-five cycles (a total of 200 hours at 200°C and 800 hours in salt spray), an arbitrary criterion for excellent protection. Three principal groups of coated panels were tested:

(1) Cadmium coatings over bronze, copper, electroless nickel and cadmium strikes, respectively. These coatings were 5.1, 7.5, and 12.7 μm (.0002, .0003 and .0005") thick corresponding to the three classes in

Specification QQ-P-416C. Additionally, two thicker cadmium coatings, 17.8 and 25.4 μm (.0007 and .001") over a copper strike were tested in this group. All cadmium coatings were chromate coated.

(2) Electroless nickel only. This group included single and duplex coatings of proprietary coatings designated Electroless Nickel I, II and III, respectively. The proprietary coatings were applied by the plating bath manufacturer. All other electroless nickel was applied in-house over a zincate immersion coating. Coating thicknesses were 12.7 and 25.4 μm (.0005 and .001").

(3) Electroless nickel plus cadmium and a chromate conversion coating. Most of these coatings were baked at 149°C (300°F) for one hour after the electroless nickel layer was applied, and baked again after cadmium plating and chromate treating. Overall coating thickness ranged from 7.6 to 25.4 μm (.0003 to .001").

Additionally, bare 6061 aluminum alloy, MIL-C-5541B chemical conversion coating, and MIL-A-8625C, Type II, sulfuric acid anodize with a dichromate seal, were cyclic corrosion tested.

Three panels of each variable were tested with the exception of some of the proprietary electroless nickel coatings for which only one panel was available.

Plating conditions are given in Appendix A.

SCRIBED PANEL TESTS

Some of the most promising coatings were evaluated in these tests as well as some less protective coatings used for comparison. Coated 48.8 x 97.6 cm (2" x 4") panels were scribed with an "X" to the basis metal and exposed for 168 hours, one set in standard 5% salt spray and one in SO_2-salt spray. SO_2 is injected into the salt spray box four times a day creating a much more corrosive atmosphere. Appendix B gives details. This test has been found to produce corrosion in aluminum alloys that is very similar to the type encountered in naval aircraft service.

DISSIMILAR METAL TESTS

In an attempt to determine galvanic corrosion effects between the various coatings and 7075-T6 aluminum alloy, or 6 Al-4V titanium alloy, 25.4 x 97.6 mm (1" x 4") cleats of bare 7075 and bare 6-4 were bolted to the coated 50.8 x 97.6 mm (2" x 4") panels and exposed to 5% salt spray for 168 hours. The aluminum and titanium alloys chosen for the cleats are the ones most often used in airframes.

HEATING - EXPOSURE TESTING

A few of the coatings were tested using one extended cycle consisting of 100 hours at 200°C, followed by 500 hours in 5% salt spray. It was hoped that

this cycle would produce the same results obtained with many shorter cycles which are less convenient to run.

RESULTS AND DISCUSSION

Results of cyclic corrosion tests, given in Table I, Figures 1 through 4, indicate the types of failures encountered. The experiments with various strikes for cadmium indicate that only one of the strikes, electroless nickel, provides a better protective system than the conventional copper strike. It should be noted, however, that this "strike" was actually 2.5 μm (.0001") thick, which is thicker than normal for strike coatings. Adhesion obtained with the cadmium strike, given in ASTM B253, was very poor. Coatings blistered and peeled after one cycle. Based on galvanic compatibility, this strike should have been the best. The bronze strike resulted in excellent adhesion, but poor cyclic corrosion behavior. Cadmium coatings up to 12.7 μm (.0005") thick pitted in less than six cycles with the exception of the coatings applied over an electroless nickel strike. It was thought that thicker cadmium coatings (copper strike), 17.8 μm (.0007") and 25.4 μm (.001"), might withstand the test better. The 25.4 μm (.001") coating did withstand the full twenty five cycles, but the 17.8 μm (.0007") coating did not. It failed in 5, 8, and 13 cycles, respectively, on the three test panels.

Twenty-three electroless nickel coated panels failed in from one to eleven cycles. Many of these failures appeared to be by a combination of severe blistering and pitting. Coating thicknesses ranged from 12.7 μm (.0005") to 25.4 μm (.001").

The best results in cyclic corrosion tests were obtained with 17.8 μm (.0007") of electroless nickel, followed by baking for one hour at 149°C, cadmium plating to a thickness of 7.6 μm (.0003"), chemical conversion coating (chromate), and baking again for one hour at 149°C (shown in Figure 5). When it was found, (1) that baking was needed to prevent blister formation (improve adhesion), and (2) that this coating showed no sign of pitting after twenty-five cycles of testing, a series of experiments was begun to find the limiting thicknesses of the respective layers. Results of this series of tests indicate that the nickel layer can go as low as 5.1 μm (.0002"), if the cadmium layer is 12.7 μm (.0005") or more, while the cadmium layer can be 5.1 μm (.0002") if the nickel layer is at least 12.7 μm (.0005").

The chromate coating for the nickel cadmium series was applied before baking rather than after. Some of the plating literature states that baking is detrimental to the corrosion resistance of chromate coatings. This difference is of little practical importance, however, when the connectors are intended for use at 200°C, and baking does result in the darker coatings required for some applications. If the connectors are to be used at lower temperatures, baking should be completed before chromating.

TABLE I

CYCLIC CORROSION TEST RESULTS

(One cycle = 16 hrs at 200°F, 32 hrs in 5% salt spray)

COATING SYSTEM	CYCLES TO FAILURE	
	Blisters	Pits **
STRIKES FOR CADMIUM *		
Copper Strike, 5.1 µm (.0002") Cadmium	N, N, N	1, 3, 3
" " 7.6 µm (.0003") "	1, 1, 2	2, 2, 2
" " 12.7 µm (.0005") "	N, N, N	4, 5, 15
" " 17.8 µm (.0007") "	N, N, N	5, 8, 13
" " 25.4 µm (.001") "	N, N, N	25, 25, 25 ***
Electroless Nickel Strike, 5.1 µm (.0002") Cadmium	2, 2, 9	4, 6, 25 ***
" " " 7.6 µm (.0003") "	4, 4, 4	6, 23, 25 ***
" " " 12.7 µm (.0005") "	2, 2, 4	25, 25, 23 ***
Cadmium Strike, 5.1 µm (.0002") Cadmium	1, 1, 1	1, 1, 1
" " 7.6 µm (.0003") "	1, 1, 1	1, 1, 1
" " 12.7 µm (.0005") "	1, 1, 1	1, 1, 1
Bronze Strike, 5.1 µm (.0002") Cadmium	N, N, N	2, 2, 2
" " 7.6 µm (.0003") "	N, N, N	2, 2, 2
" " 12.7 µm (.0005") "	N, N, N	2, 2, 2
ELECTROLESS NICKEL ONLY		
12.7 µm (.0005") Electroless Nickel	4, 4, N	4, 4, 25 ***
25.4 µm (.001") Electroless Nickel, baked 1 hr at 149°C (300°F)	N, N, N	5, 6, 10
10.2 µm (.0004") Electroless Nickel I over 2.5 µm (.0001") Electroless Nickel II	N, N, N	1, 1, 1
22.9 µm (.0009") Electroless Nickel I over 2.5 µm (.0001") Electroless Nickel II	N, N, N	1, 1, 1
12.7 µm (.0005") Electroless Nickel III over 2.5 µm (.0001") Electroless Nickel II	N, N, N	3, 3, 3
22.9 µm (.0009") Electroless Nickel III over 2.5 µm (.0001") Electroless Nickel II	N, N, N	3, 6, 6
12.7 µm (.0005") Electroless Nickel I	N	3
25.4 µm (.001") " " I	N	4
12.7 µm (.0005") Electroless Nickel II	N	3
25.4 µm (.001") " " II	N	4
12.7 µm (.0005") Electroless Nickel III	N	7
25.4 µm (.001") " " III	N	11
ELECTROLESS NICKEL PLUS CADMIUM *		
12.7 µm (.0005") Electroless Nickel, No Bake, 5.1 µm (.0002") Cadmium, No Bake	N, N, N	2, 25, 25 ***
7.6 µm (.0003") Cadmium	1, 1, 2	4, 4, 4
5.1 µm (.0002") Electroless Nickel, 149°C Bake, 5.1 µm (.0002") Cadmium, 149°C Bake	N, N, N	2, 2, 6
7.6 µm (.0003") " " "	N, N, N	5, 5, 10
12.7 µm (.0005") " " "	N, N, N	25, 25, 25 ***
12.7 µm (.0005") Electroless Nickel, 149°C Bake, 5.1 µm (.0002") Cadmium, 149°C Bake	N, N, N	25, 25, 25 ***
7.6 µm (.0003") " " "	N, N, 11	25, 25, 25 ***
12.7 µm (.0005") " " "	N, N, N	25, 25, 25 ***
17.8 µm (.0007") Electroless Nickel, 149°C Bake, 5.1 µm (.0002") Cadmium, 149°C Bake	N, N, N	25, 25, 25 ***
7.6 µm (.0003") " " "	N, N, N	25, 25, 25 ***
12.7 µm (.0005") " " "	N, N, N	25, 25, 25 ***
CHEMICAL FILM		
MIL-C-5541B, Class 3	N, N, N	25, 25, 25 ***
SULFURIC ACID ANODIZE		
MIL-A-8625C, Type II	N, N, N	25, 25, 25 ***
BARE 6061-T6 ALUMINUM	General corrosion - does not pit	25, 25, 25 ***

* All cadmium coatings were chromate conversion coated
** Cycles to failure by pitting. Six pits constitute failure.
*** No failure. Test discontinued after 25 cycles.

N = No blistering of the coating

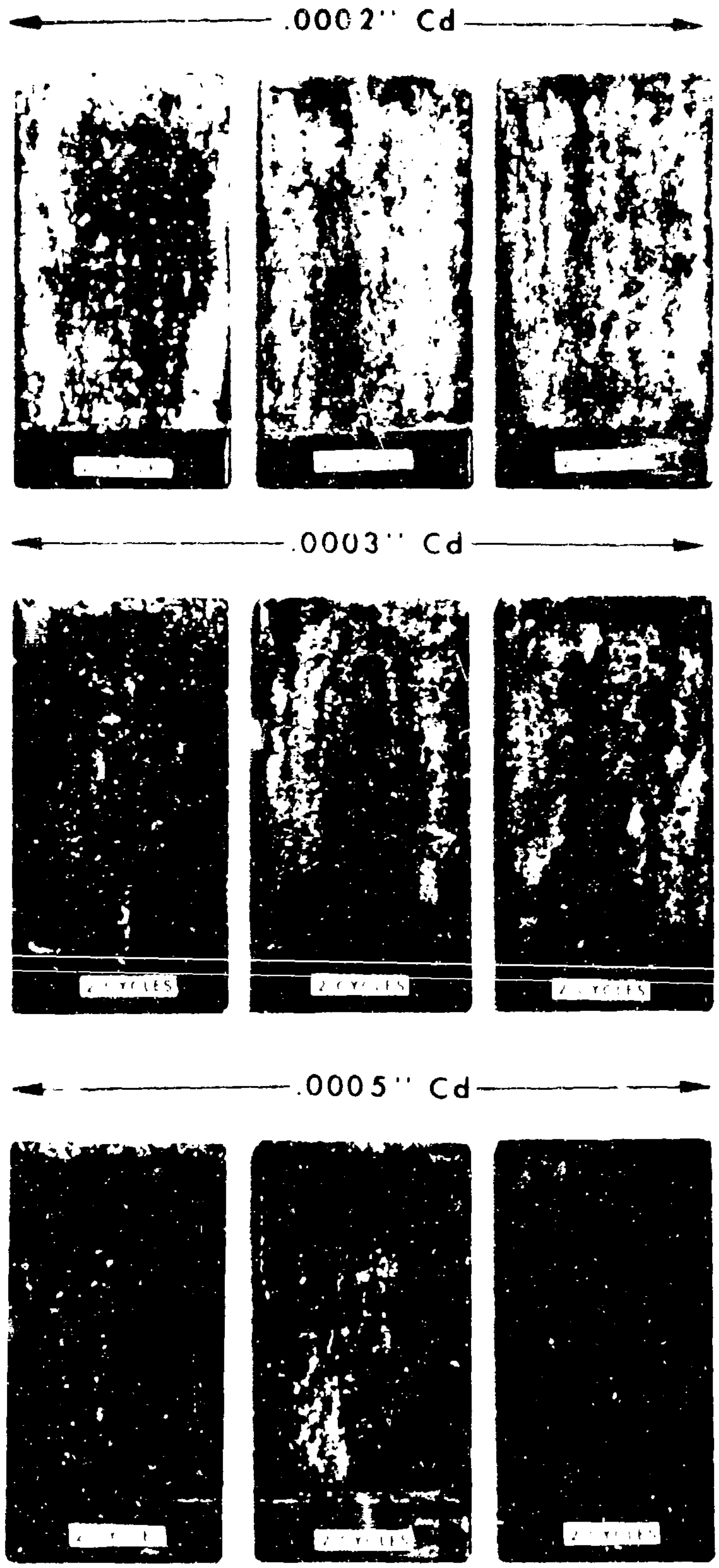

Figure 1. CYCLIC HEATING/CORROSION RESULTS
Cadmium Coatings over a Bronze Strike

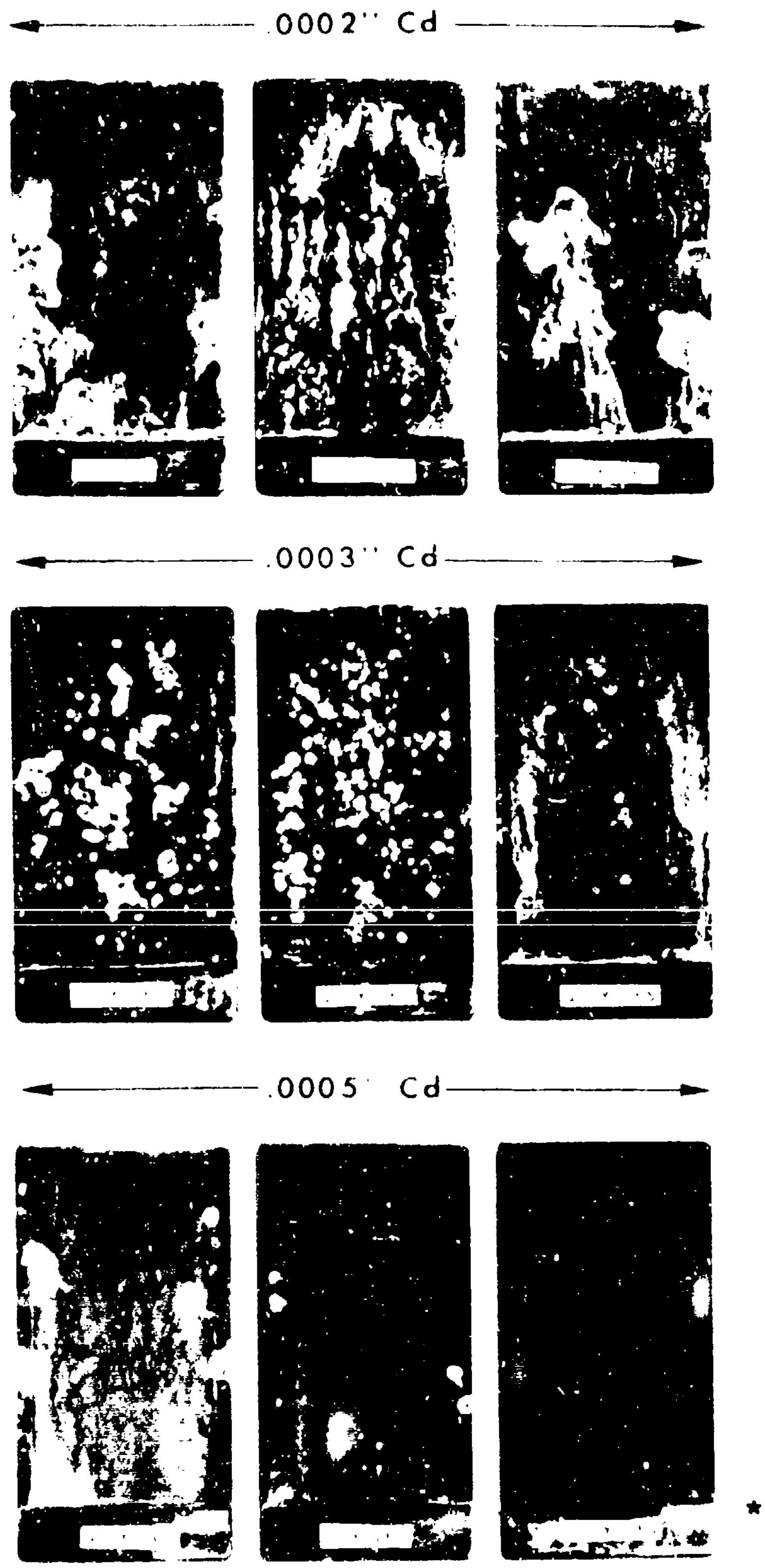

Figure 2. CYCLIC HEATING/CORROSION RESULTS
Cadmium Coatings Over a copper Strike

* This panel was returned to test and failed in 15 cycles

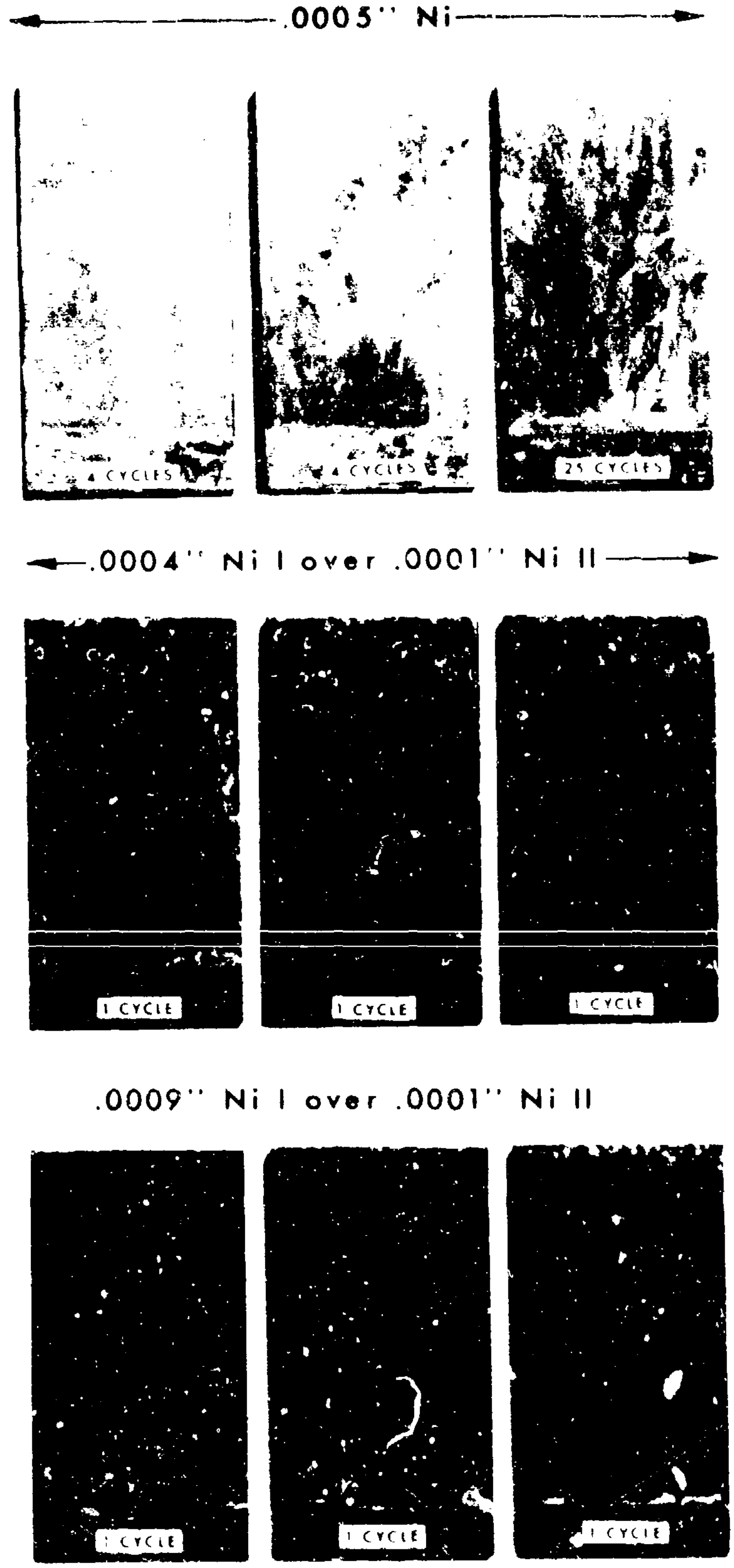

Figure 3. CYCLIC HEATING/CORROSION RESULTS Electroless Nickel Coatings

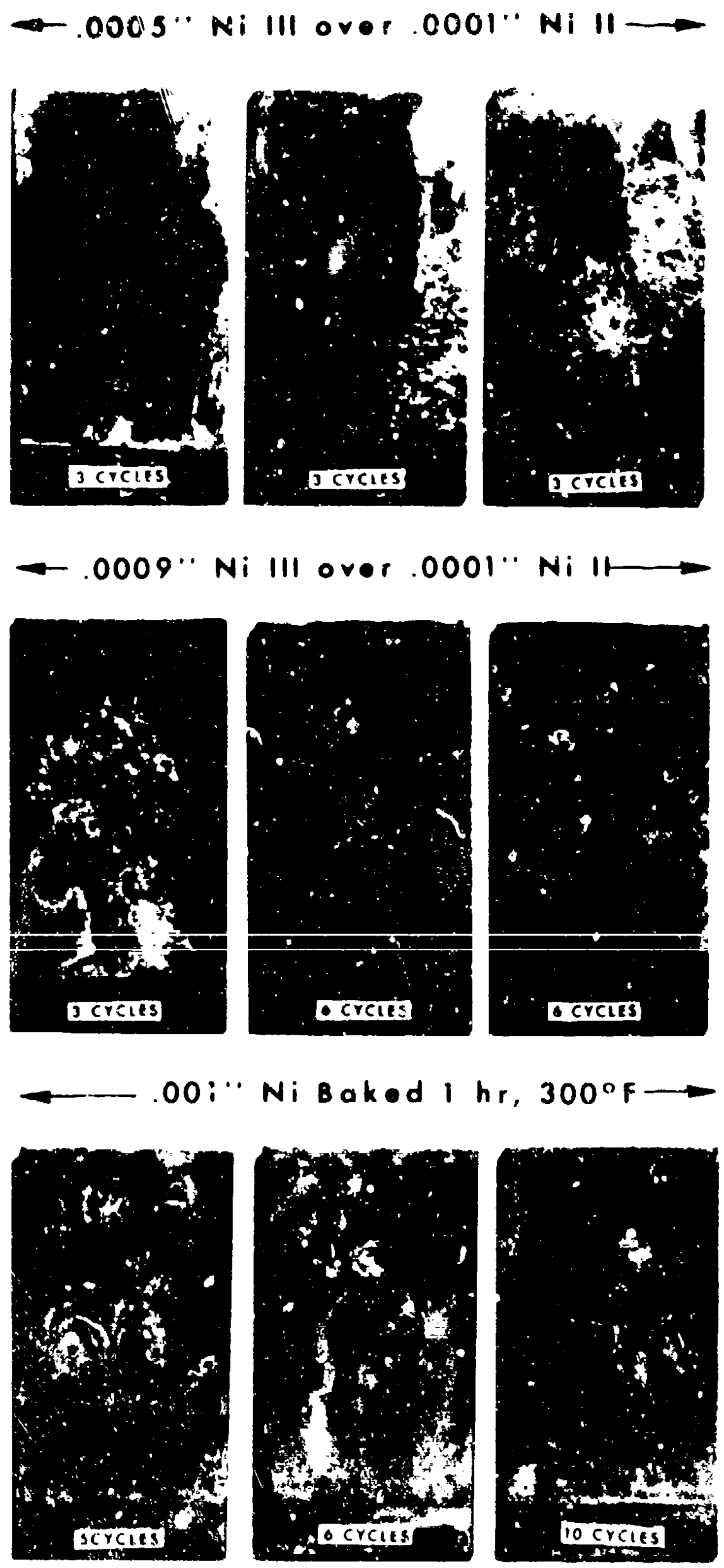

Figure 4. CYCLIC HEATING/CORROSION RESULTS
Electroless Nickel Coatings

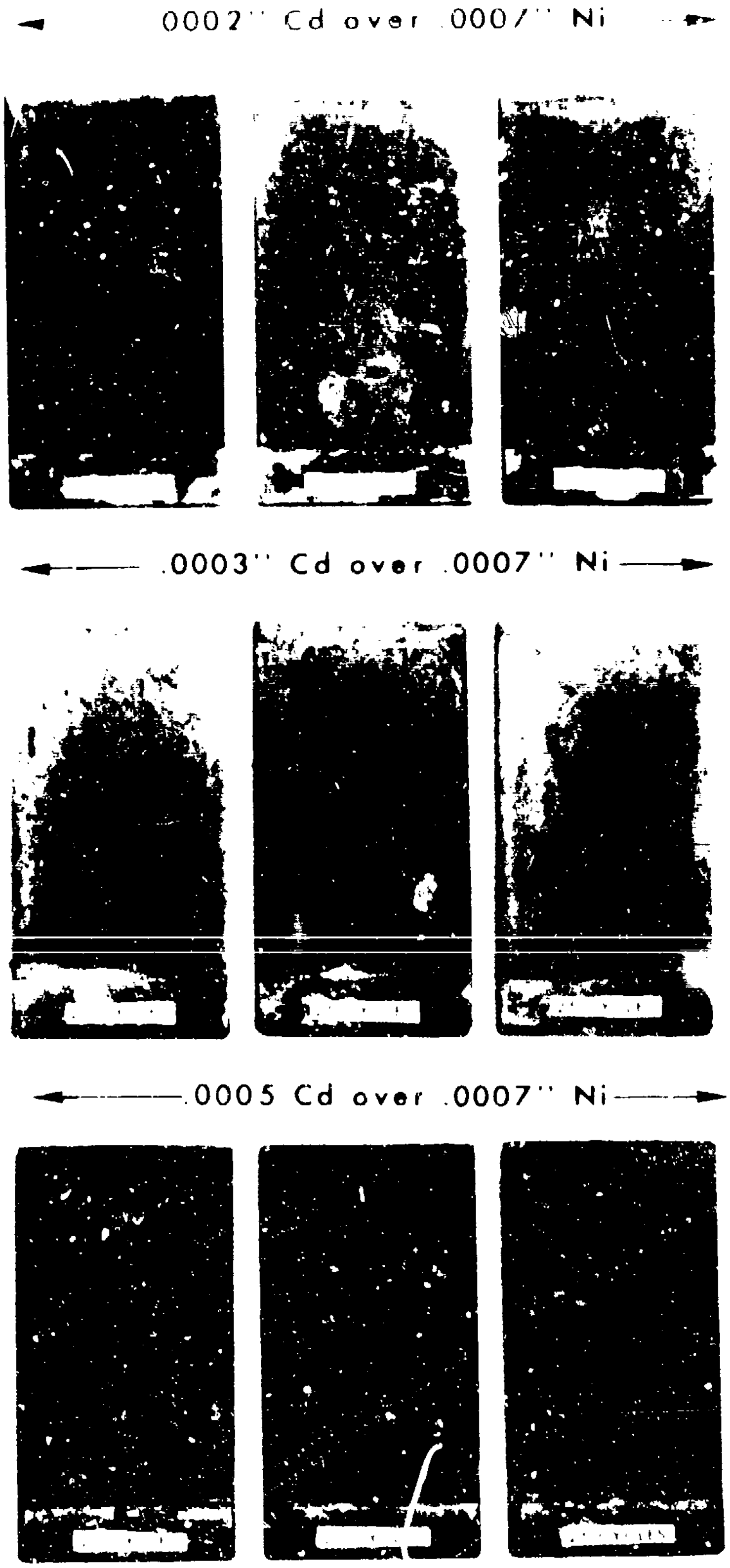

Figure 5. CYCLIC HEATING/CORROSION RESULTS
Electroless Nickel, Bake, Cadmium, Chromate Bake

As indicated earlier in this report, 6061 aluminum alloy uncoated, MIL-C-5541B, Class 3 coated, or sulfuric acid anodized with a dichromate seal all withstood twenty-five cycles of testing. The anodized panels showed only one pit in one panel, while the bare and conversion coated panels show general but very shallow pitting not considered cause for rejection.

Results of scribed panel tests in SO_2-salt spray were striking. These are given in Table II and Figure 6, for the nickel-cadmium coating, thick cadmium, 25.4 μm (.001") and thick electroless nickel, 25.4 μm. The electroless nickel appears to be intact in this photograph and it is. A better view of what has occurred is given in Figure 7. The nickel layer lifted off the underlying aluminum alloy and very severe attack of the aluminum took place. This is the condition reported for connectors in service. Some blistering occurred in the nickel-cadmium, but it was still protecting the aluminum at the end of the 168 hour exposure period. The cadmium showed considerable corrosion, especially in the scribe marks.

Scribed panel tests in the standard 5% salt spray agreed generally with the SO_2-salt spray tests, but results were not as easily interpreted. Scribes in the nickel cadmium showed only a few pits as opposed to many pits in the cadmium coating. Results are given in Table III.

Dissimilar metal test results failed to show any outstanding differences in the behavior of electroless nickel-cadmium coatings and coatings of cadmium alone over a copper strike. In both cases, there was pitting along the edge of the cleat. Pitting was slightly more pronounced in the case of the titanium cleats, but still appeared to be only in the coating. Corrosion between the bare 7075 and bare 6061 aluminum alloys appears to be almost as bad as corrosion between the coated panels and the 7075 cleats. In all cases, the corrosion probably takes place by a combination of crevice and galvanic corrosion. Figures 8 and 9 illustrate some of the results and Table IV gives details.

The attempt to shorten cyclic testing times by substituting one extended cycle (100 hours at 200°C followed by 500 hours in 5% salt spray) for the repeated short cycles was unsuccessful in that the results showed electroless nickel to be satisfactory when service experience indicates that it is not. Once again, nickel-cadmium passed the tests with no pitting, only a considerable darkening of the film. Thick cadmium (25.4 μm) showed some pitting, but was otherwise generally good. Thinner cadmium coatings failed. Results are given in Table V in greater detail.

Careful review of all the tests conducted indicates that the most rapid test method that gives meaningful results is the SO_2-salt spray test. However, SO_2-salt spray equipment is not generally available. It is, therefore, considered that the cyclic corrosion test is a better specification type test. This test could be shortened to ten cycles, if it were required that three specimens pass the test. The inadequacy of salt spray testing alone is at least suggested by the long cycle test (100 bake followed by 500 hour salt spray), in which electroless nickel appears to be satisfactory.

TABLE II

SCRIBED PANEL TEST RESULTS

(SO_2 Salt Spray - 168 hr Exposure)

Coating	Results
Cadmium 5.0 µm (.0002") Copper Strike	Poor - all three panels corroded and pitted
Cadmium 17. µm (.0007") Copper Strike	Considerable corrosion - especially in scribes (three panels)
Cadmium 25.4 µm (.001") Copper Strike	Considerable corrosion - especially in scribes (three panels)
Electroless Nickel 17.8 µm (.0007 Cadmium 7.6 µm (.0003") (Baked after each layer)	Excellent by comparison with others - No pits, some blistering, much yellowing of coating. Some light white corrosion. Scribes good in all three
Electroless Nickel 25.4 µm (.001") (Baked 1 hr at 149°C)	Very poor - nickel lifted away from aluminum in one sheet. Aluminum badly corroded. All three panels the same.

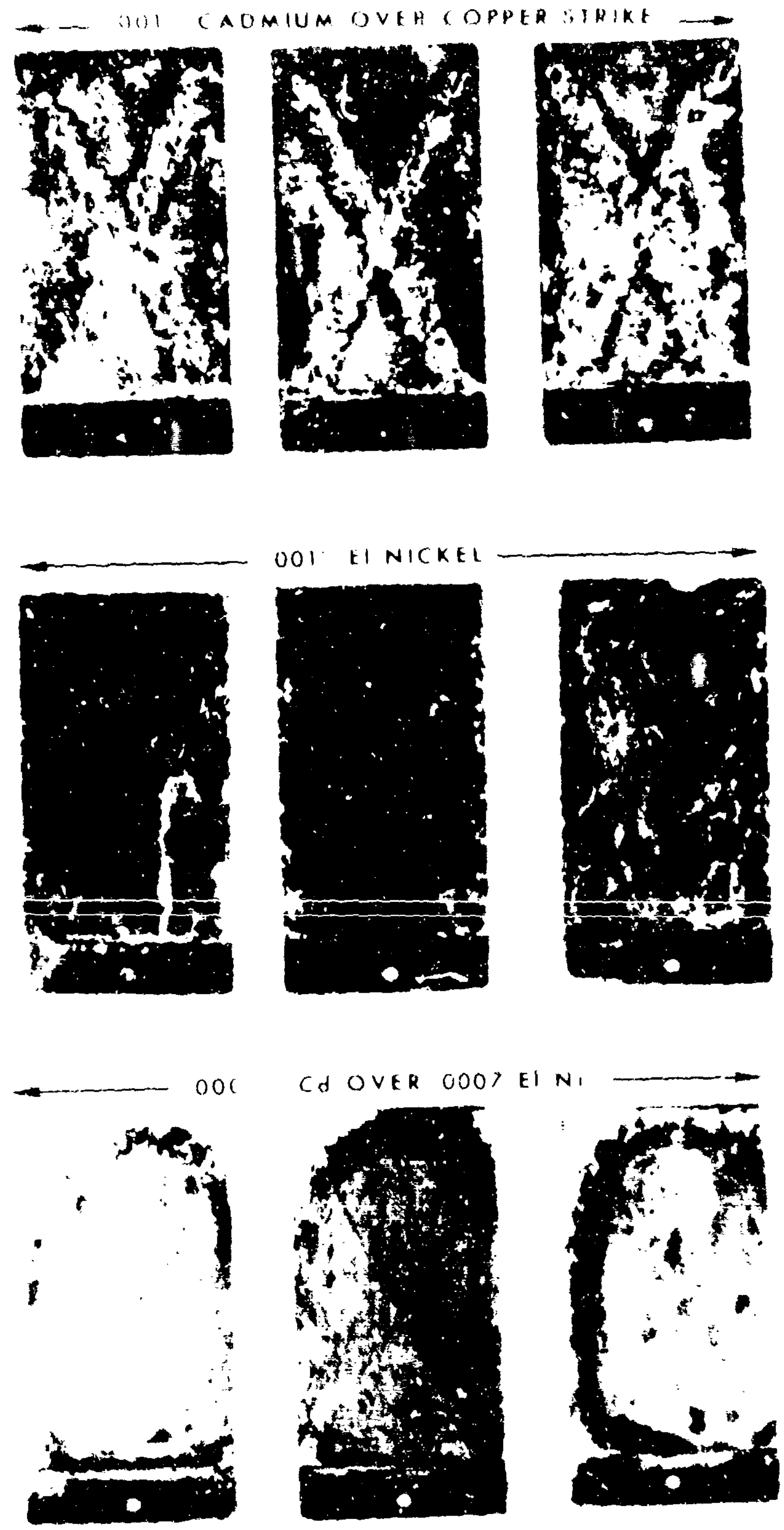

Figure 6. Results of 168 hour SO_2-Salt Spray Exposure

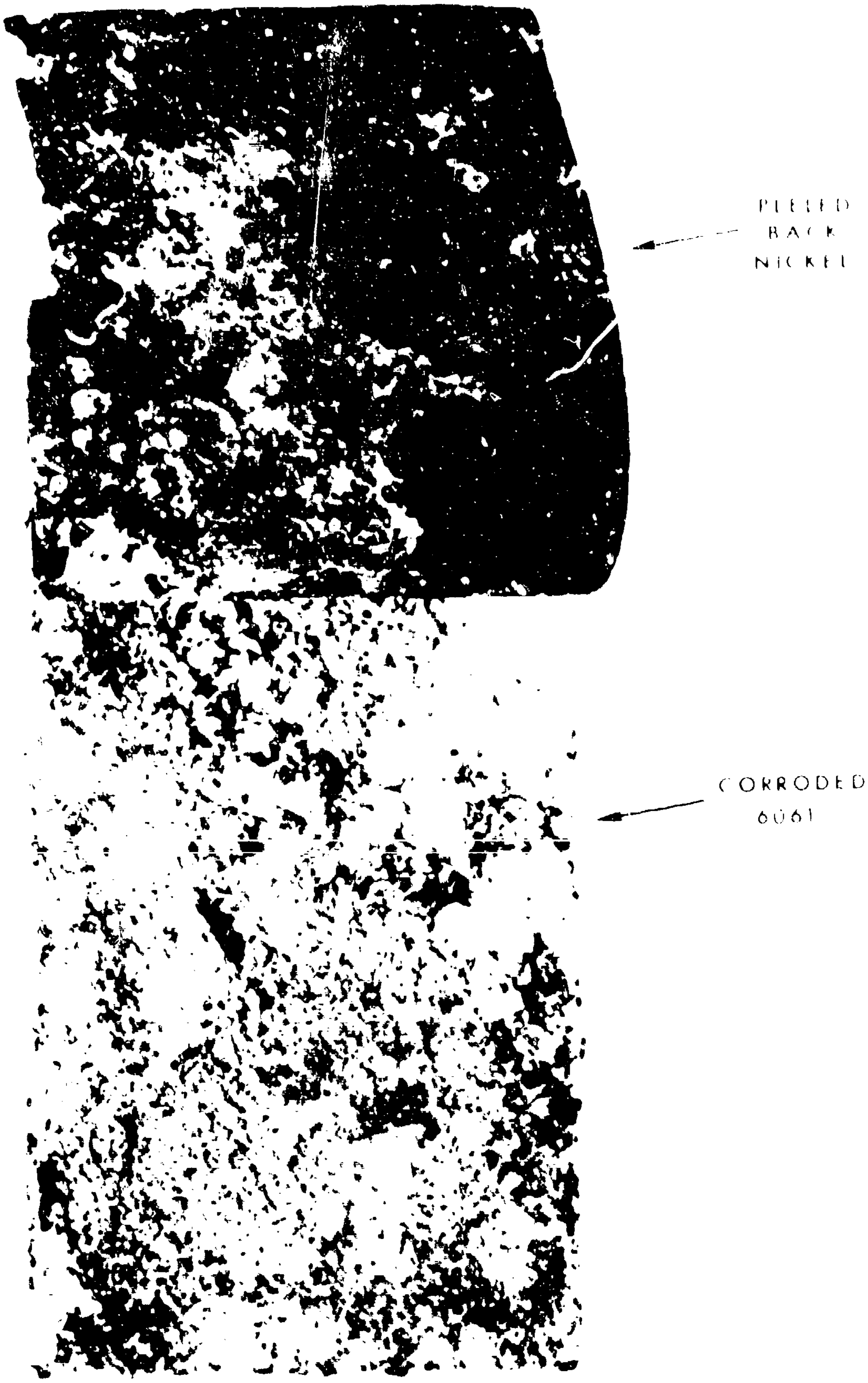

Figure 7. Electroless Nickel .001" over 6061 Aluminum Alloy - 168 hours Exposure to SO_2-Salt Spray

TABLE III

SCRIBED PANEL TEST RESULTS

(5% Salt Spray - 168 hr Exposure)

	Coating	Results
*	Cadmium 25.4 µm (.001") Copper Strike	White corrosion fills ¼ to ½ of the scribes. Pits are forming.
*	MIL-C-5541 Chemical Film	Good - no pits, slight corrosion
*	Sulfuric Acid Anodize	Good - no pits, very slight corrosion
**	El Ni 5.0 µm (.0002") Cadmium 5.0 µm (.0002")	Some white corrosion, 3 pits
**	El Ni 5.0 µm (.002") Cadmium 7.6 µm (.0003")	Good - slight white corrosion in scribe
**	El Ni 5.0 µm (.0002") Cadmium 12.7 µm (.0005")	Good - very little white corrosion in scribe
**	El Ni 12.7 µm (.0005") Cadmium 7.6 µm (.0003")	Good - little white corrosion
**	El Ni 12.7 µm (.0005") Cadmium 12.7 µm (.0005")	Good - slight white corrosion
**	El Ni 17.8 µm (.0007") Cadmium 7.6 µm (.0003")	Good - very slight white corrosion
**	El Ni 17.8 µm (.0007") Cadmium 12.7 µm (.0005")	Good - very slight white corrosion

* Three panels of each

** One panel of each - all baked after nickel coating and baked again after cadmium coating and chromating.

TABLE IV

DISSIMILAR METAL TEST RESULTS

7075-T6 ALUMINUM CLEATS ATTACHED TO COATED PANELS (168 hrs in Salt Spray)

Coating	Panel	Cleat
None - Control Panels	Good - some very slight pitting of faying surfaces	Some general corrosion faying surfaces
Cadmium 25.4 µm (.001")	Good - slight white corrosion lines at cleat edges. Very light corrosion of faying surfaces	Much general corrosion of faying surface
El Ni 5 µm (.002") Cadmium 7.6 µm (.0003") El Ni 5 µm (.0002") Cadmium 12.7 µm (.0005") El Ni 12.7 µm (.0005") Cadmium 7.6 µm (.0003") El Ni 12.7 µm (.0005") Cadmium 12.7 µm (.0005") El Ni 17.8 µm (.0007") Cadmium 5 µm (.0002") El Ni 17.8 µm (.0007") Cadmium 7.6 (.0003") El Ni 17.8 µm (.0007") Cadmium 12.7 µm (.0005")	All generally the same - Good - white corrosion along edge lines and slight corrosion in faying surfaces (very shallow pit ing)	Some light corrosion - very light pitting of faying surfaces in all cleats

6 Al 4V TITANIUM CLEATS ATTACHED TO COATED PANELS (168 hrs in Salt Spray)
(None of the Cleats were corroded)

Cadmium 25.4 µm (.001")	Good - some very small pits along cleat edge
El Ni 5 µm (.0002") Cadmium 7.6 µm (.0003") El Ni 5 µm (.0002") Cadmium 12.7 µm (.0005") El Ni 12.7 µm (.0005") Cadmium 7.6 µm (.0003") El Ni 12.7 µm (.0005") Cadmium 12.7 µm (.0005") El Ni 17.8 µm (.0007") Cadmium 7.6 µm (.0003") El Ni 17.8 µm (.0007") Cadmium 12.7 µm (.0005")	All panels similar - slight white corrosion along cleat edge lines with very slight attack of faying surfaces. The last panel in the series was slightly better than the rest.
El Ni 17.8 µm (.0007") Cadmium 5 µm (.0002")	Distinct pitting along one cleat edge. Remainder same as others.

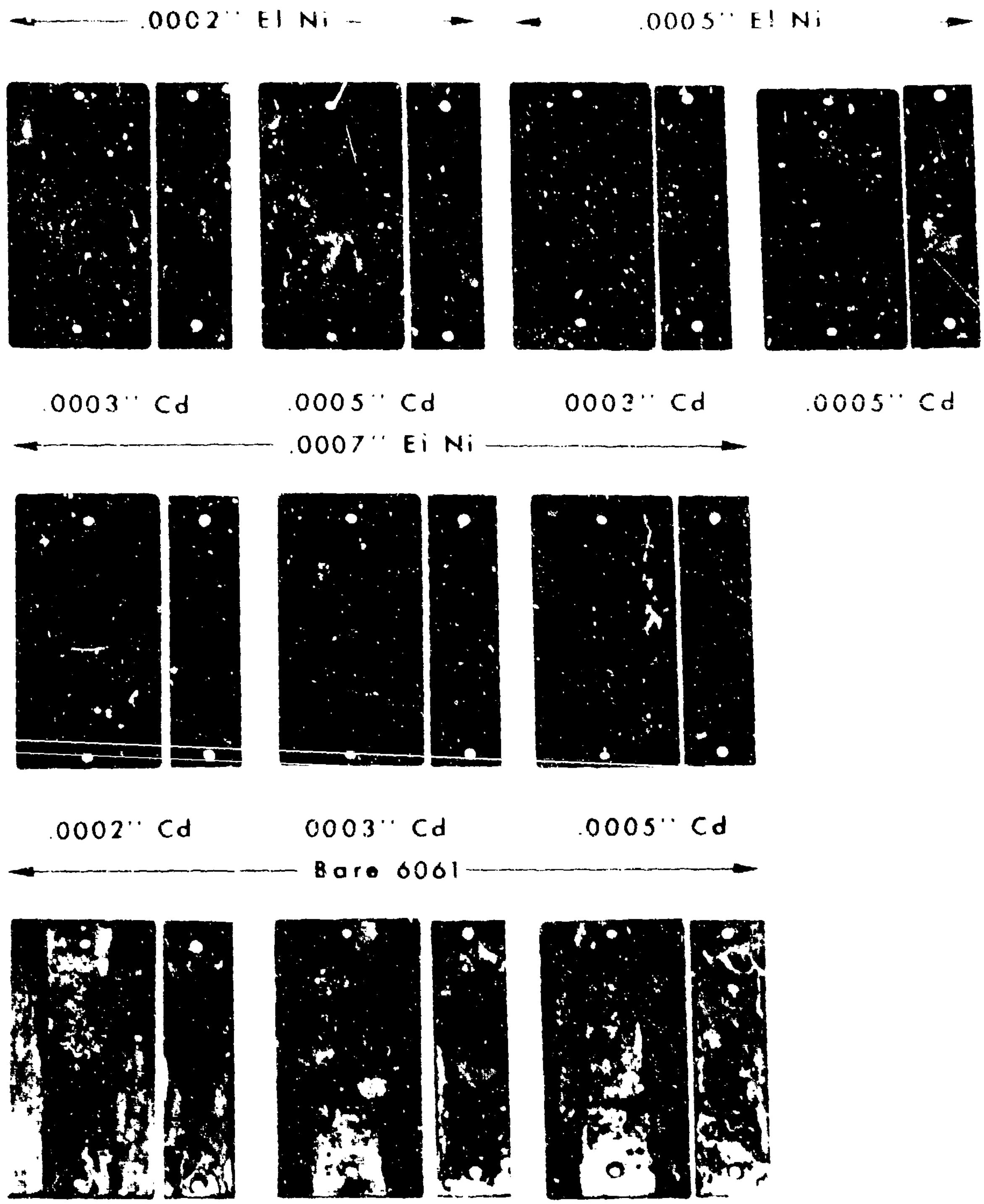

Figure 8. Electroless Ni-Cadmium Coatings and Bare 6061-T6 Aluminum Alloy Coupled to 7075-T6 Aluminum Alloy - 168 hrs 5% Salt Spray

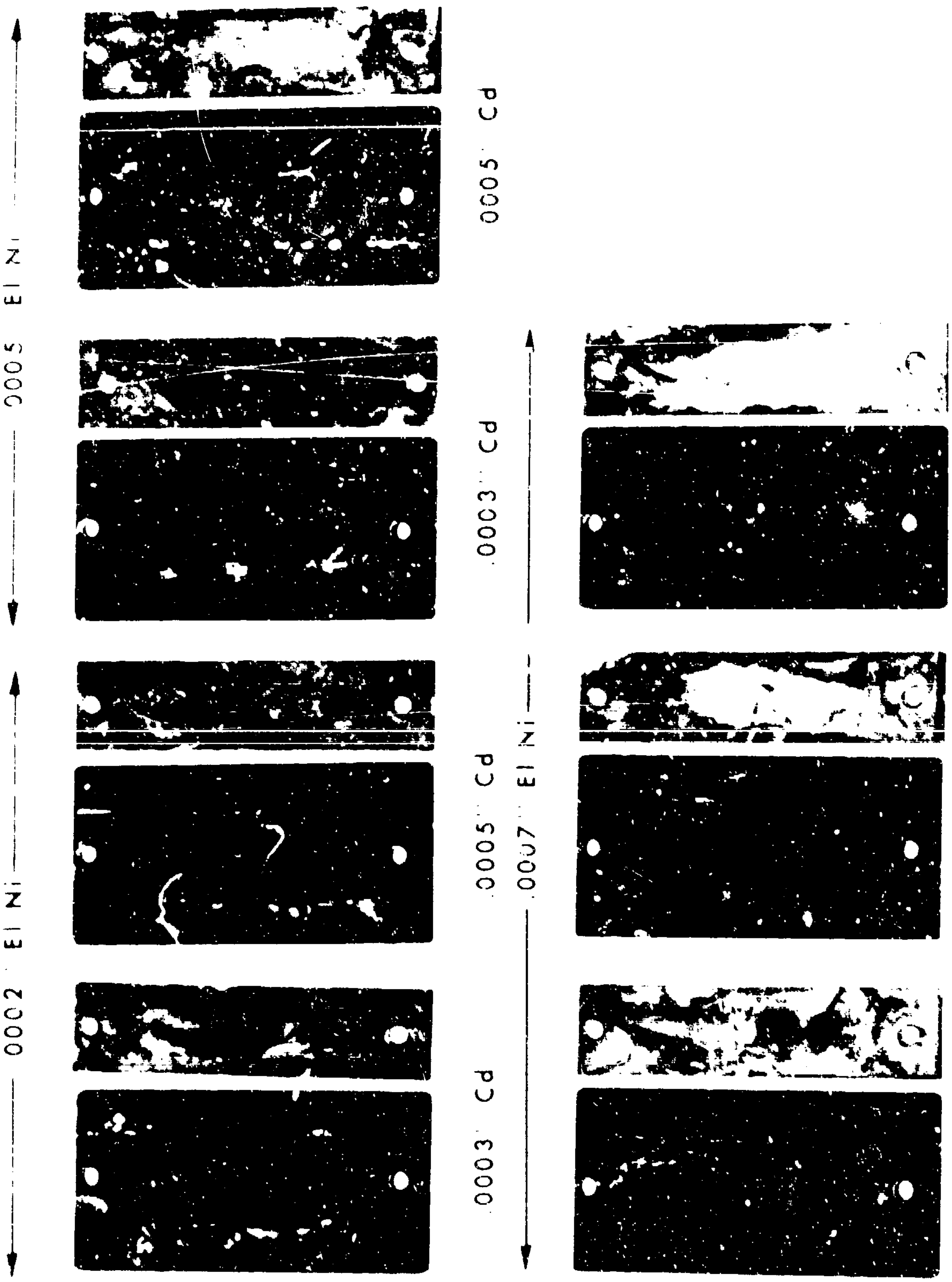

Figure 9. Electroless Ni-Cadmium Coatings Coupled to 6Al-4V-Titanium Alloy - 158 hrs in 5% Salt Spray

TABLE V

LONG CYCLE TEST RESULTS

(100 hrs at 200°C plus 500 hrs in 5% Salt Spray)

Coating	Results
5.1 μm (.0002") Cadmium * over Copper Strike	General heavy white corrosion over all three panels - very bad
17.8 μm (.0007") Cadmium * over Copper Strike	Considerable pitting in all panels
25.4 μm (.001") Cadmium * over Copper Strike	One panel more than six pits; one, three; one, edge pits. All show general light white corrosion
17.8 μm (.0007") Electroless Nickel, Bake, 7.6 μm (.0003") Cadmium, Chromate, Bake	Good - one pit on one panel - general darkening of panel centers
25.4 μm (.001") Electroless Nickel	Overall appearance good in all three

* All chromated

Some discussion of the definition of failure appears to be warranted. Failure, as defined by electronics engineers, appears to be non-functioning of the equipment. From an aircraft corrosion control standpoint, general pitting or blistering of a coating is considered failure. In a sense both definitions are probably correct. As long as the part performs its function, it has not failed. On the other hand, many manhours are spent trying to prevent further deterioration of corroded parts that still function and these manhours are not considered wasted because corroded connectors will ultimately fail mechanically or electrically, if corrosion is not stopped. The most reasonable solution is to apply finishes that will last the life of the aircraft. The corrosion test requirements of connector specifications, such as MIL-C-5015, are not stringent enough to assure good corrosion resistant finishes. It is for that reason that it is recommended that a more severe test, such as some form of cyclic corrosion test, replace the very loose requirements now in effect; (i.e., no exposure of basis metal due to corrosion that will affect performance after 48 hours of salt spray exposure). The requirement should also include a better criterion for evaluating finishes, such as the appearance of six pits or blistering of the coating.

While the work performed in this investigation was directed toward finding better coatings for service up to 200°C, it should be noted that QQ-P-416, Class 3, Type II cadmium plating (5.1 μm) performed poorly in all the tests. This poor behavior is probably caused by the galvanic effect between the conventional copper strike and the thin, porous cadmium layer, as well as between the copper and the basis metal. It is felt that consideration should be given to increasing the thickness requirement for low temperature classes of connectors from Class 3 to Class 1 (12.5 μm (.0005") for better corrosion protection.

Some actual connector parts of both 6061 wrought aluminum alloy and 380 casting alloy have been coated with various systems and are being tested in both SO_2-sal spray and cyclic heating-corrosion (5% NaCl). Early results indicate that the complex configuration of the shells (threads, projections, ridges, etc.) make early failure more likely than it is in panel testing. Additionally, some surfaces of the connectors are in a horizontal position during salt spray exposure, no matter how the parts are suspended, and these surfaces will be more severely attacked. Results of these tests will be reported as soon as they are completed.

APPENDIX A

PLATING CONDITIONS

APPENDIX A

PLATING CONDITIONS

I PLATING CYCLE

A. Non etch alkaline clean, 71-82°C (160-180°F), 10 min
B. Warm water rinse, 45-50°C (112-121°F)
C. Mild etch, 60-64°C (140-147°F), 2-4 min
D. Warm water rinse, 45-50°C (112-121°F)
E. Cold water rinse
F. Desmut, room temperature, 10-60 sec
G. Double cold water rinse
H. Modified zincate, room temperature, 1 min
I. Cold water rinse, 1 min
J. 50% HNO_3, 30-60 sec
K. Cold water rinse, 1-2 min
L. Modified zincate, 10 sec
M. Cold water rinse, 1-2 min
N. Strike or go directly to electroless nickel
O. Cold water rinse
P. Plate
Q. Double cold water rinse
R. Chromate treat cadmium coatings
S. Double cold water rinse
T. Dry

II CYCLE FOR ELECTROLESS [illegible]-CADMIUM

A. Same as I - A through O
B. Bake 1 hr at 149°C (300°F)
C. Dip in 25% HCl, 5 sec
D. Rinse
E. Cadmium plate
F. Rinse
G. Chromate treat
H. Rinse
I. Dry
J. Bake 1 hr at 149°C (300°F)

III PLATING SOLUTIONS

Zincate Immersion Bath per ASTM B253, Bath I
Copper Strike per ASTM B253
Cadmium Strike per ASTM B253

APPENDIX A

Bronze Strike
Proprietary - Alstan 80, 30 sec, 108 A/m^2 (10 A/ft^2), 29°C (85°F), followed by Alstan 71, 4 min, 323 A/m^2 (30 A/ft^2), 29°C (85°F)

Cadmium Plate

Cadmium Oxide	30 g/l (4 oz/gal)
Sodium Cyanide	120 g/l (16 oz/gal)
Brightener	Udylite 53 as required
Room temperature	
Current density	215 A/m^2 (20 A/ft^2)

Electroless Nickel
Proprietary - 10.5% phosphorus 82-88°C (180-190°F)

Non-Etch Alkaline Cleaner

Oakite 164	45-60 g/l (6-8 oz/gal)
	71-83°C (160-180°F)

Mild Etch Cleaner

Oakite 160	30 g/l (4 oz/gal)
	38-71°C (100-160°F)

Desmut (Proprietary chromate type)

Isoprep 188	120 g/l (16 oz/gal)
	Room temperature

Chromate Conversion Coating

Iridite No. 1	30 sec, room temperature
1 Part 1A	
1 Part 1B	
10 Parts water	

APPENDIX B

SO_2 - SALT SPRAY
(SIMULATED AIRCRAFT CARRIER ENVIRONMENT)

A P P E N D I X   B

SO. - SALT SPRAY
(SIMULATED AIRCRAFT CARRIER ENVIRONMENT)

APPARATUS:

Salt fog cabinet meeting requirements of ASTM recommended Practice B117-73, Appendix 1.

Test conducted in accordance with ASTM B117-73 with the following exceptions:

Tower Temperature	45.5°C ± 1
Cabinet Temperature	35°C ± 1

SO_2 gas injection - 1 hr/6hr cycle continuously

SO_2 gas flow - 25 cc/min

CONDITIONS IN COLLECTION BOTTLE
(Tested Weekly)

(1) 1 to 2 mls/hr collection rate

(2) pH - 1.8 - 2.5

(3) Sp-gr - 1.025 - 1.040

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